Guest Editorial
Special Issue on Cognitive Learning of Multiagent Systems

THE DEVELOPMENT and cognition of biological and intelligent individuals shed light on the development of cognitive, autonomous, and evolutionary robotics. Take the collective behavior of birds as an example, each individual effectively communicates information and learns from multiple neighbors, facilitating cooperative decision making among them. These interactions among individuals illuminate the growth and cognition of natural groups throughout the evolutionary process, and they can be effectively modeled as multiagent systems. Multiagent systems have the ability to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve, which also improves the robustness and efficiency through collaborative learning. Multiagent learning is playing an increasingly important role in various fields, such as aerospace systems, intelligent transportation, smart grids, etc. With the environment growing increasingly intricate, characterized by factors, such as high dynamism and incomplete/imperfect observational data, the challenges associated with various tasks are escalating. These challenges encompass issues like information sharing, the definition of learning objectives, and grappling with the curse of dimensionality. Unfortunately, many of the existing methods are struggling to effectively address these multifaceted issues in the realm of cognitive intelligence. Furthermore, the field of cognitive learning in multiagent systems underscores the efficiency of distributed learning, demonstrating the capacity to acquire the skill of learning itself collectively. In light of this, multiagent learning, while holding substantial research significance, confronts a spectrum of learning problems that span from single to multiple agents, simplicity to complexity, low dimensionality to high dimensionality, and one domain to various other domains. Agents autonomously and rapidly make swarm intelligent decisions through cognitive learning overcoming the above challenges, which holds significant importance for the advancement of various practical fields.

This special issue aims to explore cognitive learning in multiagent systems from an application-oriented perspective, encompassing practical applications, such as cognitive, autonomous, and evolutionary robotics, among others. As one of the important branches of artificial intelligence, emerging cognitive learning is promising to enhance learning efficiency and to make swarm intelligent decision making of cooperative/competitive/cooperative–competitive multiagent systems. Given this, the purpose of this special issue is to address challenging bottleneck problems of extending cognitive learning to multiagent systems in practical application scenarios.

In order to realize the aforementioned goals, the guest editors of this special issue of IEEE TRANSACTIONS ON COGNITIVE AND DEVELOPMENTAL SYSTEMS (TCDS) have comprehensively evaluated the originality, quality, and relevance of all the submitted papers. Through a rigorous and careful review process, 11 high-quality papers have been selected for publication. Collectively, these papers offer viable and intriguing approaches from various cognitive learning perspectives, aiming to improve the decision-making capabilities of multiagent systems. Through these selected papers, researchers can intuitively understand the states-of-the-art, challenges, and future directions in applying computational intelligence to multiagent systems. The details of these papers are given below.

In the aspect of the application of cognitive learning in multiagent systems, five of the selected papers covering federated cognitive learning and distributed cognitive learning are dedicated to solving process monitoring, and human–robotic interaction issues in cooperative–competitive multiagent systems. Specifically, the article by Chen et al. [A1] proposes a cognitive-learning-based method that can reduce the computation loads in both offline and online phases, because only necessary information exchange (or communication topology) is involved. Case studies on the wastewater treatment system demonstrate the superiority of the proposed distributed process-monitoring method.

Considering the integration of distributed cognitive learning into cooperative–competitive multiagent systems, the article by Liu et al. [A2] studies the distributed cognitive learning algorithm of cooperative–competitive multiagent systems on undirected graphs. A bipartite consensus learning strategy is designed for the disturbance-free case, enabling agents to cognitively learn cooperative and adversarial information transmitted by their neighbors. For the case with boundary disturbances, a cognitive learning algorithm is designed, in which agents constantly adjust their behavior by sensing the external environment to make complex behavioral decisions.

Taking into account the protection of user privacy in the process of cognitive learning, the article by Shi et al. [A3] proposes pFedEff, a personalized federated learning framework with efficient communication that can reduce communication volume and preserve training accuracy to solve either large

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communication volumes or large accuracy losses in traditional communication optimizations. The experimental results show that pFedEff reduces up to 94% communication volume with only a 1% accuracy loss over other state-of-the-art federated learning algorithms.

The article by Li et al. [A4] proposes an observer-based distributed event-triggered iterative learning control framework, in which distributed state observers provide the indispensable state information for agents to learn to complete the task. With locally Lipschitz nonlinearities and iteration-varying uncertainties caused by nonrepetitive initial states, the double-dynamics analysis method is adopted to illustrate the convergence of the ILC process.

To develop neurocognitive models incorporating anthropoid behaviors into robots, the article by Tavassoli et al. [A5] studies different motion and behavior learning methods ranging from movement primitives to experience abstraction, applied to different robotic tasks. These methods undergo thorough scrutiny and are subsequently experimentally benchmarked through the reconstruction of a standard pick-and-place task.

In the aspect of the application of reinforcement learning in multiagent systems, four of the selected papers covering continual reinforcement learning and prior knowledge-augmented broad reinforcement learning are dedicated to solving tracking control, mobile-edge computing, fault diagnosis, and human–robotic interaction issues in heterogeneous or robotic multiagent systems. Specifically, the article by Xu and Wu [A6] employs a reinforcement learning technique to investigate the distributed output tracking control of heterogeneous multiagent systems under multiple denial-of-service attacks, on the condition that the leader's system matrix is completely unknown for each follower. To consider the transient responses of agents, an RL-based dynamic output-feedback controller is developed to realize the optimal output tracking control by solving discounted algebraic Riccati equations in both offline and online ways.

Considering the control of redundant musculoskeletal and robotic systems, the article by Chen et al. [A7] proposes a neural manifold-modulated continual reinforcement learning method, which is inspired by the developmental mechanisms in the motor cortex. The experimental results suggest that it can realize continual reinforcement learning of multiple tasks in different movements and environments.

By incorporating reinforcement learning algorithms into task offloading in mobile-edge computing, the article by Ding et al. [A8] proposes a task offloading scheduling strategy which combined multiagent reinforcement learning and meta-learning to solve the problem that conventional deep RL algorithms cannot adapt to dynamic environments. To efficiently train the policy network, a first-order approximation method based on clipped surrogate objective is proposed.

In light of the unpredictability of faults occurring in heterogeneous multiagent systems, the article by Guo et al. [A9] proposes a novel framework called prior-knowledge-augmented broad reinforcement learning to effectively diagnose faults in a heterogeneous MAS. A novel fault diagnosis framework based on broad reinforcement learning with prior knowledge is proposed that effectively integrates offline reinforcement learning and broad learning into the fault diagnosis process.

In the aspect of the game framework of multiagent systems, two of the selected papers concerning cooperative multiagent systems and multiagent multiobjective game are dedicated to solving distributed confrontation decision-making problem. Specifically, the article by Ma et al. [A10] proposes a multilayer games framework that integrates cognition, decision making, and countermeasures. Through the transformation of agent preference to alliance communication structure, a cooperation–competition topology network model is constructed, which improves the convergence and solution efficiency of the game model.

Considering cooperative multiagent systems, the article by Li et al. [A11] proposes a distributed adversarial decision-making approach for multiagent system, which is supposed to detect a team of intelligent targets. To achieve higher detection benefits, a new variant of the distributed alternating direction method of multipliers is introduced to search for the optimal solutions under the worst defense policy that the targets choose.

In summary, this special issue presents 11 key papers that propose advanced and novel cognitive learning technologies to substantially improve the intelligent decision-making ability of multiagent systems. As guest editors, we would like to express our sincere thanks to all the authors who submitted their work to this special issue, and all the reviewers for their great efforts in ensuring the quality of the selected papers. In addition, we would like to express our heartiest gratitude for the great support of the Editor-in-Chief, Prof. Huajin Tang, and the editorial office throughout the editing process of this special issue. We hope that all the selected papers can further accelerate the development of multiagent systems with cognitive learning in various application fields, such as industrial manufacturing, intelligent transportation, and evolutionary robotic, to name a few.

APPENDIX: RELATED ARTICLES

[A1] H. Chen, O. Dogru, S. K. Varanasi, X. Yin, and B. Huang, "Distributed process monitoring for multiagent systems through cognitive learning," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 8–19, Feb. 2024.

[A2] Y.-J. Liu, S. Zhang, and L. Tang, "Distributed cognitive learning strategy for cooperative–competitive multiagent systems," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 20–30, Feb. 2024.

[A3] H. Shi, J. Zhang, S. Fan, R. Ma, and H. Guan, "pFedEff: An efficient and personalized federated cognitive learning framework in multiagent systems," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 31–45, Feb. 2024.

[A4] H. Li, J. Luo, H. Ma, and Q. Zhou, "Observer-based event-triggered iterative learning consensus for locally Lipschitz nonlinear MASs," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 46–56, Feb. 2024.

[A5] M. Tavassoli, S. Katyara, M. Pozzi, N. Deshpande, D. G. Caldwell, and D. Prattichizzo, "Learning skills from demonstrations: A trend from motion primitives to experience abstraction," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 57–74, Feb. 2024.

[A6] Y. Xu and Z.-G. Wu, "Data-based collaborative learning for multiagent systems under distributed denial-of-service attacks," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 75–85, Feb. 2024.
[A7] J. Chen, Z. Chen, C. Yao, and H. Qiao, "Neural manifold modulated continual reinforcement learning for musculoskeletal robots," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 86–99, Feb. 2024.
[A8] W. Ding, F. Luo, C. Gu, Z. Dai, and H. Lu, "A multiagent meta-based task offloading strategy for mobile edge computing," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 100–114, Feb. 2024.
[A9] L. Guo, Y. Ren, R. Li, and B. Jiang, "Prior knowledge-augmented broad reinforcement learning framework for fault diagnosis of heterogeneous multiagent systems," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 115–123, Feb. 2024.
[A10] X. Ma, Y. Zhang, W. Xie, J. Yang, and W. Zhang "Multiagent multiobjective decision making and game for saving public resources," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 124–140, Feb. 2024.
[A11] Y. Li, H. Liu, F. Sun, and Z. Chen, "Adversarial decision making against intelligent targets in cooperative multiagent systems," *IEEE Trans. Cogn. Develop. Syst.*, vol. 16, no. 1, pp. 141–150, Feb. 2024.

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